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6. AUTHOR(S) F. J. Samaniego, Principal Investigator		
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) University of California, Davis 1 Shields Avenue Davis, CA 95616		8. PERFORMING ORGANIZATION REPORT NUMBER 004
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13. ABSTRACT (Maximum 200 words)

A detailed description is given of the Principal Investigator's research accomplishments during the three year period (5/99 – 4/02) over which the PI's research was supported through the above named contract. Work in the areas of a) combining information from disparate sources, b) network reliability, c) software reliability, d) modeling and inference in reliability and e) general statistical research is featured. Twenty-five research papers related to this period are specifically listed in the report.

14. SUBJECT TERMS reliability, nonparametric inference, hierarchical Bayes inference, networks, software				15. NUMBER OF PAGES 6
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REPORT DOCUMENTATION PAGE (SF298)
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FINAL REPORT

1. **PERIOD COVERED BY REPORT: May 1, 1999 – April 30, 2002**

2. **PROPOSAL TITLE: Towards a Theory for Combining Information from Related Experiments**

3. **CONTRACT NUMBER: ARO Contract # DAAD 19-99-1-1082**

4. **AUTHOR OF THE REPORT: Francisco J. Samaniego, Principal Investigator**

5. **PERFPORMING ORGANIZATION: University of California, 1 Shields Avenue, Davis, CA 95616**

The primary focus of our research under ARO support has been problems on combining information from 'related' but non-exchangeable experiments via Bayes, linear Bayes and hierarchical Bayes methods. The prototypical example of such data combination problems is that of combining available information from developmental and operational testing in the context of the DoD acquisitions program. Our work on linear Bayes methods was developed first. In a paper (joint with Steffey and Tran) that appeared in the Proceedings of the 4th Army Conference on Applied Statistics (see paper #1 below), we demonstrated that linear Bayes procedures offer substantial potential for improving upon the inferential performance of standard procedures that ignore the information available from related life-testing experiments. We have now examined three specific Bayesian parametric paradigms: exponential-gamma, normal-normal and binomial-beta. In these three contexts, we have studied models that link parametrically the probability distributions for the observable data and capture the uncertainty regarding the linkage parameters through hierarchical Bayesian modeling.

A second phase of our study develops the fully Bayesian approach to handling data from related life-testing experiments, and sheds light on the circumstances in which full specification of the Bayes procedure offers substantial improvement upon the linear Bayes approach. This work was presented in paper # 4 below, joint with Steffey and Tran, at the International Conference on Mathematical Methods in Reliability in Bordeaux, France in July 2000.

A third paper (#22 below) provides a general treatment of modeling and inference for related experiments, and covers the three parametric paradigms mentioned above in a comprehensive manner as examples of hierarchical models involving quadratic variance functions. Also treated there are nonparametric models in which data from related experiments are modeled as being drawn from distributions having linked Dirichlet distributions.

An alternative to the approach above to treating the combining of data from related experiments is to model the experiments as related through a form of stochastic ordering. For example, it is generally the case that the lifetimes measured in operational tests tend to be smaller in value than those obtained from developmental tests. One way of modeling this situation is to postulate that the lifetimes X and Y drawn randomly from operational and developmental testing obey a stochastic ordering relationship. But the traditional formulation of stochastic ordering is a rather stringent assumption, requiring that the distribution of X is uniformly larger than that of Y. In joint work with colleagues M. A. Arcones and P. H. Kvam, the PI

identified a new and widely applicable version of such stochastic relationships, and have been investigating its properties. We say that a variable X *stochastically precedes* the variable Y if $P(X < Y) > ½$.

We began to study the problem of estimating the underlying distributions of data from related experiments when the relationship is modeled as *stochastic precedence*. Preliminary work on this inference problem was presented in October 1999 at the 5th Army Conference of Applied Statistics at West Point See paper # 7). In that paper, joint with Arcones and Kvam, we demonstrated that consistent estimators of the underlying distributions of data from experiments subject to a stochastic precedence constraint could be obtained either by rescaling or by translating data from one of the other experiment. We also showed that either of these approaches provides improvement over the empirical distribution in terms of asymptotic integrated mean squared error. A full development of the underlying theory behind these procedures was presented in paper #9.

The Principal Investigator and his co-workers, have pursued research on a variety of other statistical topics during this grant period, and acknowledges ARO support for this additional work. This additional work can be divided into five categories: General research on statistical inference in reliability (papers #2, 3, 8, 12, 13, 18, and 24), general investigations on decision theoretic topics (papers #10, 14, 15 and 20), applied statistical modeling and inference (papers # 5, 6, 11 and 23), research in structural reliability (papers # 16, 17, 19, 21) and research on software reliability (paper 25). Some of our research in network reliability (paper # 16) was presented at the 6th Army Comference of Applied Statistics in October, 2001.

Papers written or in preparation under the support of ARO Contract # DAAD 19-99-1-1082

[1] "Linear Data Fusion", Proceedings of the Fourth Army Conference on Applied Statistics, MD: Aberdeen Proving Ground (1999), 107-120, (with D. Steffey and H. Tran)

[2] "On the Asymptotic Distribution Theory for a Class of Consistent Estimators of a Distribution Satisfying a Uniform Stochastic Ordering Constraint, Annals of Statistics, (2000) 28, 116-150 (with M. Arcones)

[3] "Estimation of a Monotone Mean Residual Life", Annals of Statistics, (2000) 28, 905-921, (with S. Kochar, T. Hu, and H. Mukerjee)

[4] "Hierarchical Bayesian Inference in Related Reliability Experiments", in Recent Advances in Reliability, (N. Limnios and M. Nikulin, Editors) (2000), Boston: BirkHauser, 379-390 (with D. Steffey and H. Tran)

[5] Time Use Measurement and Research: Report of a Workshop, National Academy of Sciences Press, (2000) (Co-edited with N. Bradburn, J. DaVanzo, W. Nordhaus and S. VerPloeg)

[6] "A Nonparametric Approach to Managing Materials Quality", Transportation Research Record, 1712 (2000), 109 - 116 ((with P. Benson and Y. S. Chong)

[7] "On Combining Information from Ordered Experiments", Proceedings of the Fifth Army Conference on Applied Statistics, 51 – 65 (2001) (with M. A. Arcones and P. H. Kvam)

[8] "Estimation of Two Ordered Mean Residual Life Functions", Journal of Statistical Planning and Inference, 107 (1-2) (2002), 321-341 (with X. Hu, S. Kochar and H. Mukerjee)

[9] "On Nonparametric Estimation of Distributions Subject to a Stochastic Precedence Constraint", Journal of the American Statistical Association, 97 (2002), 170 – 182, (with M. A. Arcones and P. H. Kvam)

[10] "On Comparing Bayes Estimators to the Sample Mean in Multivariate Normal Problems," Proceedings of the Joint Statistical Meetings, ASA Bayesian Section (2002) (with E. Vestrup).

[11] "Revisiting the Notion of Induced Traffic through a Matched-Pairs Study", Transportation, 29 (2002), 193 – 220 (with P. Mokhtarian, R. Shumway and N. Willits)

[12] "Life Testing in a Weibull Environment", in Balakrishnan and Basu, A. (Editors) The Weibull Distribution: Theory, Methods and Applications, to appear (with Y. S. Chong)

[13] Reliability Issues for DoD Systems: Report on a Workshop, National Academy of Sciences Press, to appear (Edited volume with M. Cohen)

[14] "On the Comparative Performance of Bayesian and Classical Point Estimators under Asymmetric Loss", Sankhya, Series A, to appear (with D. Bhattacharya and E. Vestrup)

[15] "Asymptotic Approximations to posterior Distributions via Latent-Data Conditional Moment Equations", Biometrika, to appear (with J. Yee and W. O. Johnson)

[16] "On Computing and Comparing the Reliability of Competing Networks", Proceedings of the 7th Army Conference on Applied Statistics, to appear (with P. Boland and E. Vestrup)

[17] "The Signature of a Coherent System and its Applications in Reliability" in Singpurwalla, N. and Soyer, R. Mathematical Reliability Theory: An Expository Perspective, Klewer Press, to appear (with P. Boland)

[18] "Estimation of Cumulative incidence Functions in Competing Risks Studies Under an Order Restriction", Journal of Statistical Planning and Inference, to appear (with H. El Barmi, S. Kochar, S. and H. Mukerjee)

[19] "Stochastic Ordering Results for Consecutive k-out-of-n:F Systems", IEEE Transactions in Reliability, to appear (with P. Boland)

[20] "Bayes versus Frequentist Shrinkage in Multivariate Normal Problems," submitted for publication (with E. Vestrup).

[21] "Linking Dominations and Signatures in Network Reliability Theory", submitted for publication, (with P. Boland and E. Vestrup)

[22] "On Hierarchical and Linear Bayes Approaches to Combining Data from 'Related' Experiments", submitted for publication (with D. Steffey and H. Tran)

[23] "On Constrained Estimation from Time Use Survey Data", submitted for publication (with E. Vestrup)

[24] "A Nonparametric Test for Stochastic Precedence" submitted for publication (with M. Arcones and P. Kvam)

[25] "A Nonparametric Approach to Estimating Software Reliability", in preparation (with S. Wilson)

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Sincerely,

F. J. Samaniego, PI